

Progress in Unsteady Turbopump Flow Simulations Using Overset Grid Systems

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Outline

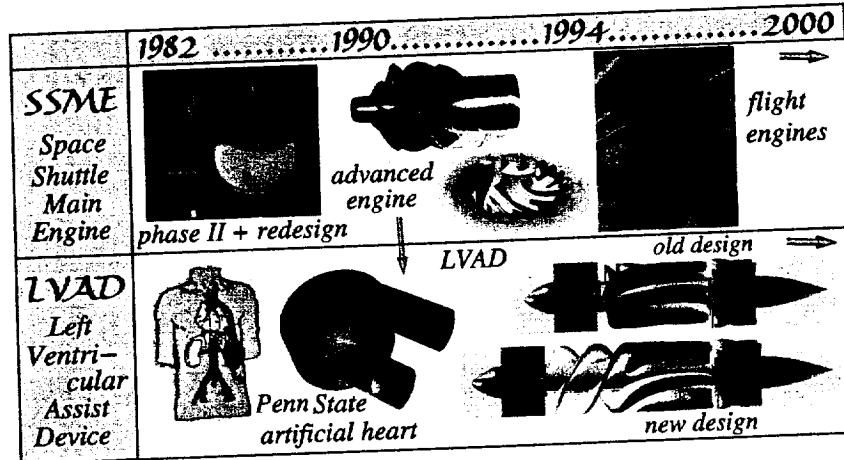
- INTRODUCTION
 - Major Drivers of the Current Work
 - Objective
- SOLUTION METHODS
 - Summary of Solver Development
 - Formulation / Approach
 - Parallel Implementation
- UNSTEADY TURBOPUMP FLOW
 - Overset Grid System
 - Scripting Capability
 - Results
- SUMMARY

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Objectives



- To enhance incompressible flow simulation capability for developing aerospace vehicle components, especially, unsteady flow phenomena associated with high speed turbo pump.



Current Challenges



- Challenges where improvements are needed
 - Time-integration scheme, convergence
 - Moving grid system, zonal connectivity
 - Parallel coding and scalability
- As the computing resources changed to parallel and distributed platforms, computer science aspects become important.
 - Scalability (algorithmic & implementation)
 - Portability, transparent coding, etc.
- Computing resources
 - "Grid" computing will provide new computing resources for problem solving environment
 - High-fidelity flow analysis is likely to be performed using "super node" which is largely based on parallel architecture



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Time Accurate Formulation



- Time-integration scheme

Artificial Compressibility Formulation

- Introduce a pseudo-time level and artificial compressibility
- Iterate the equations in pseudo-time for each time step until incompressibility condition is satisfied.

Pressure Projection Method

- Solve auxiliary velocity field first, then enforce incompressibility condition by solving a Poisson equation for pressure.

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INS3D - Incompressible N-S Solver



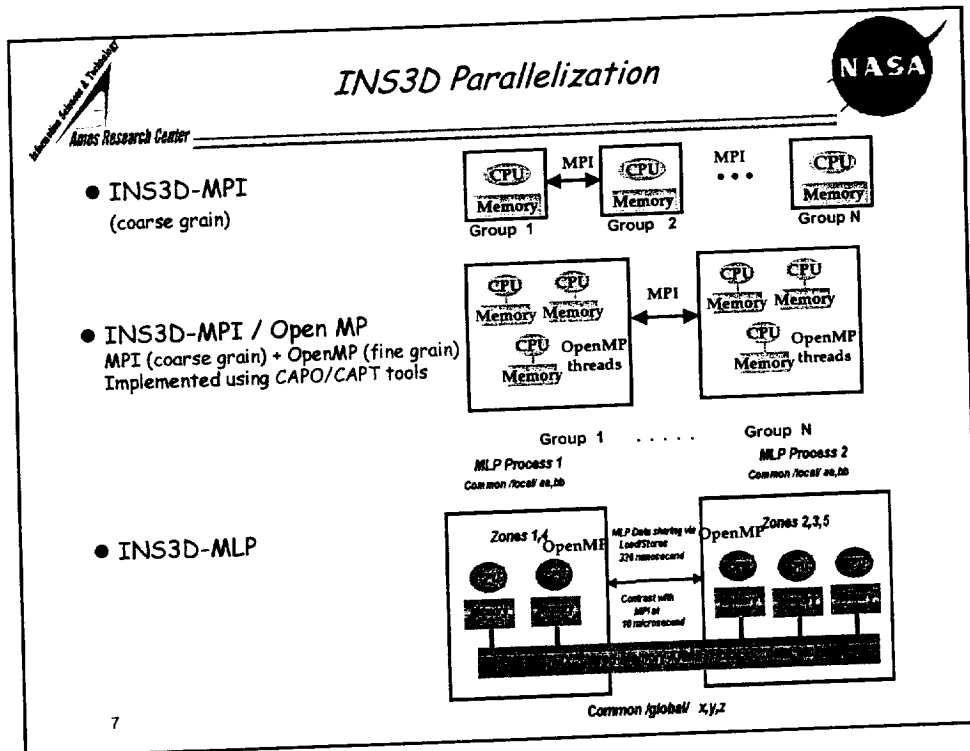
**** Parallel version is based on INS3D-UP :**

- MPI and MLP parallel versions
- Structured, overset grid orientation
- Moving grid capability
- Based on method of artificial compressibility
- Both steady-state and time-accurate formulations
- 3rd and 5th-order flux difference splitting for convective terms
- Central differencing for viscous terms
- One- and two-equations turbulence models
- Several linear solvers : GMRES, GS line-relaxation, LU-SGS, GS point relaxation, ILU(0).....

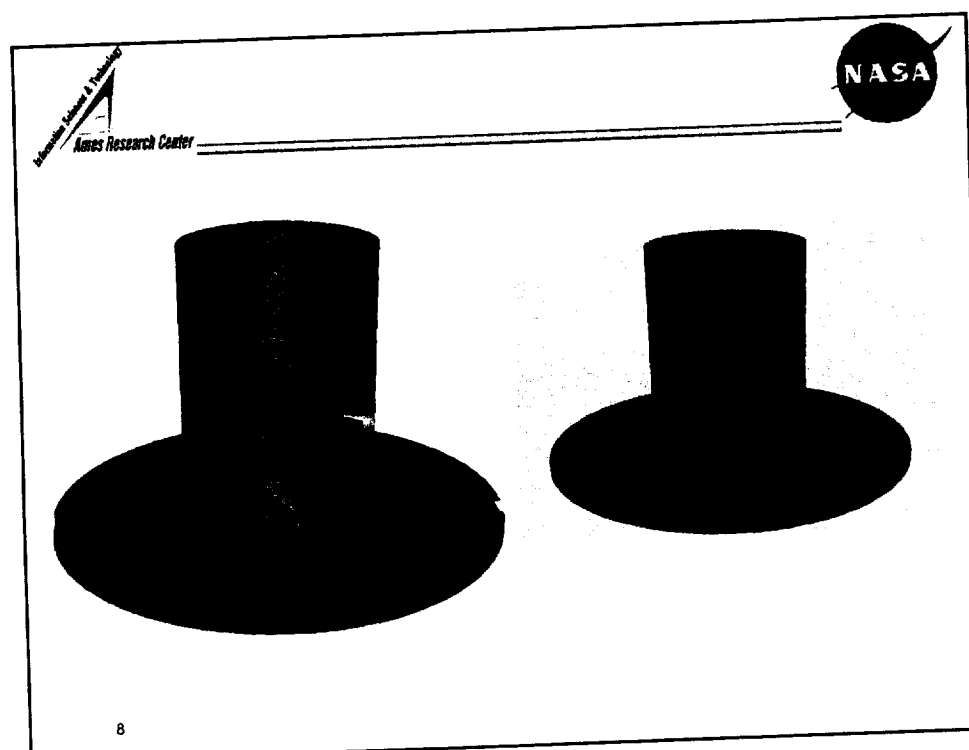
• HISTORY

- ** 1982-1987 Original version of INS3D - Kwak, Chang
- ** 1988-1999 Three different versions were devoped :
 - INS3D-UP / Rogers, Kiris, Kwak
 - INS3D-LU / Yoon, Kwak
 - INS3D-FS / Rosenfeld, Kiris, Kwak

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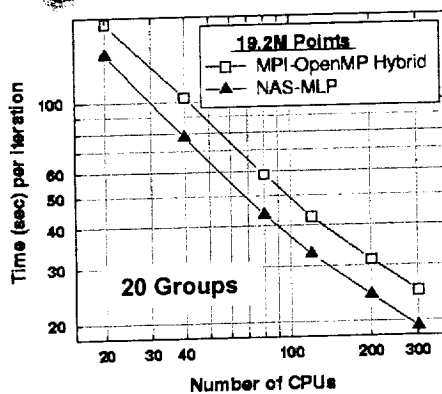
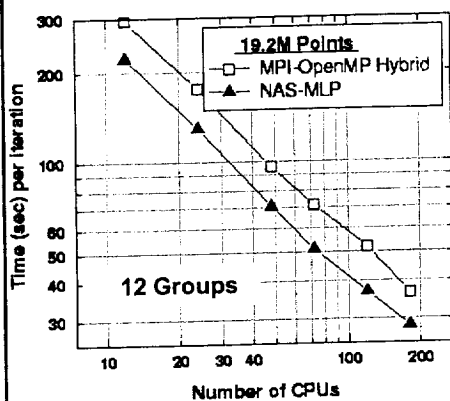


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INS3D Parallelization

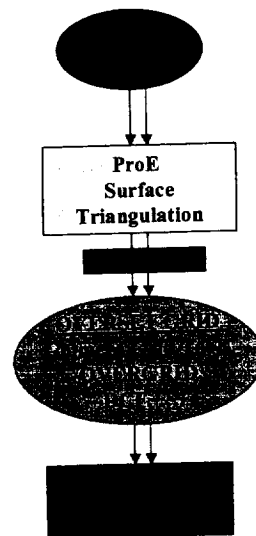
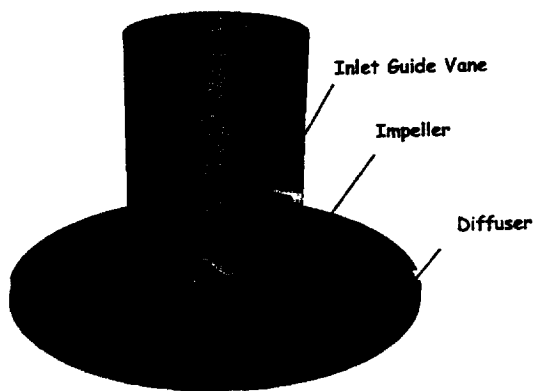
INS3D-MLP/OpenMP vs. -MPI/OpenMP

TEST CASE : SSME Impeller
60 zones / 19.2 Million points



RLV 2nd Gen Turbopump (SSME Rig1)

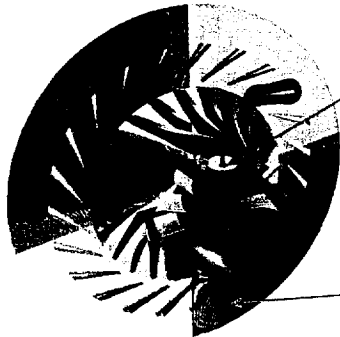
Impeller Technology Water Rig
Baseline SSME/ATD HPFTP Class Impeller



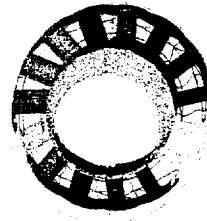
RLV 2nd Gen Turbopump

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Overset Grid System



Inlet Guide Vanes
15 Blades
23 Zones
6.5 M Points



Diffuser
23 Blades
31 Zones
8.6 M Points



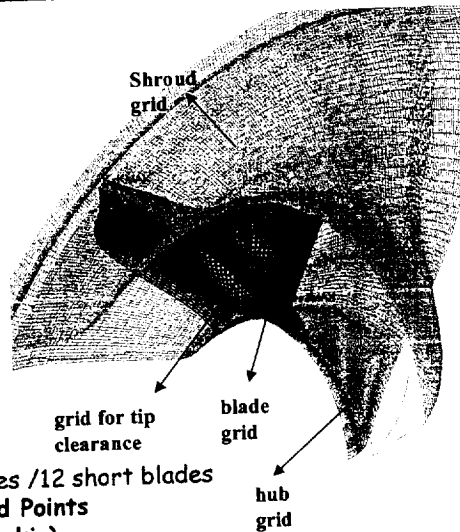
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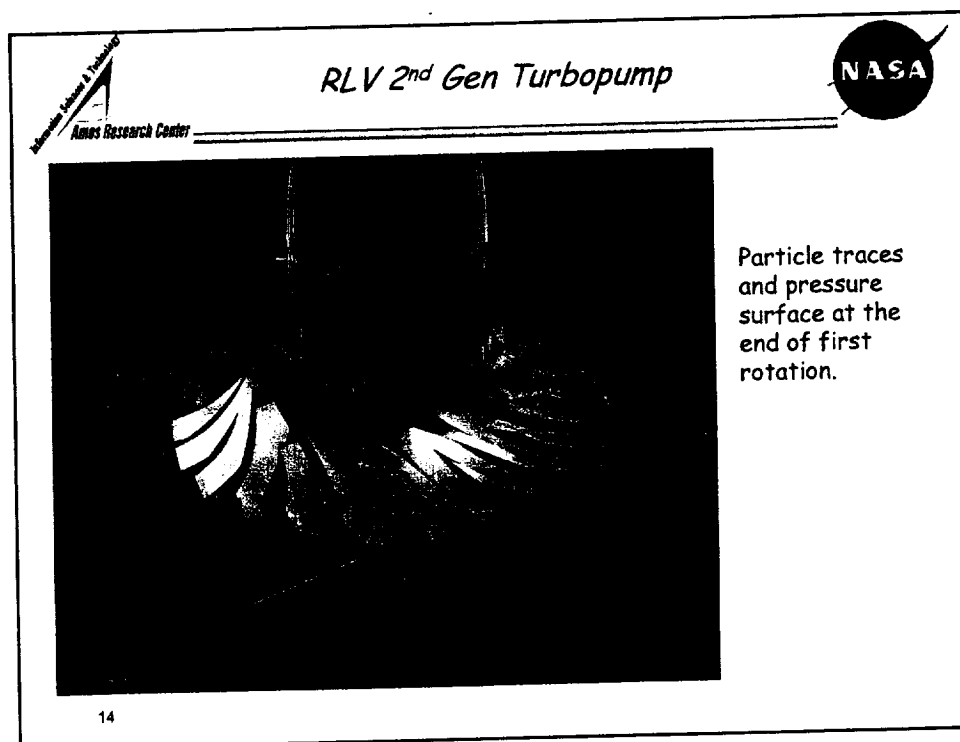
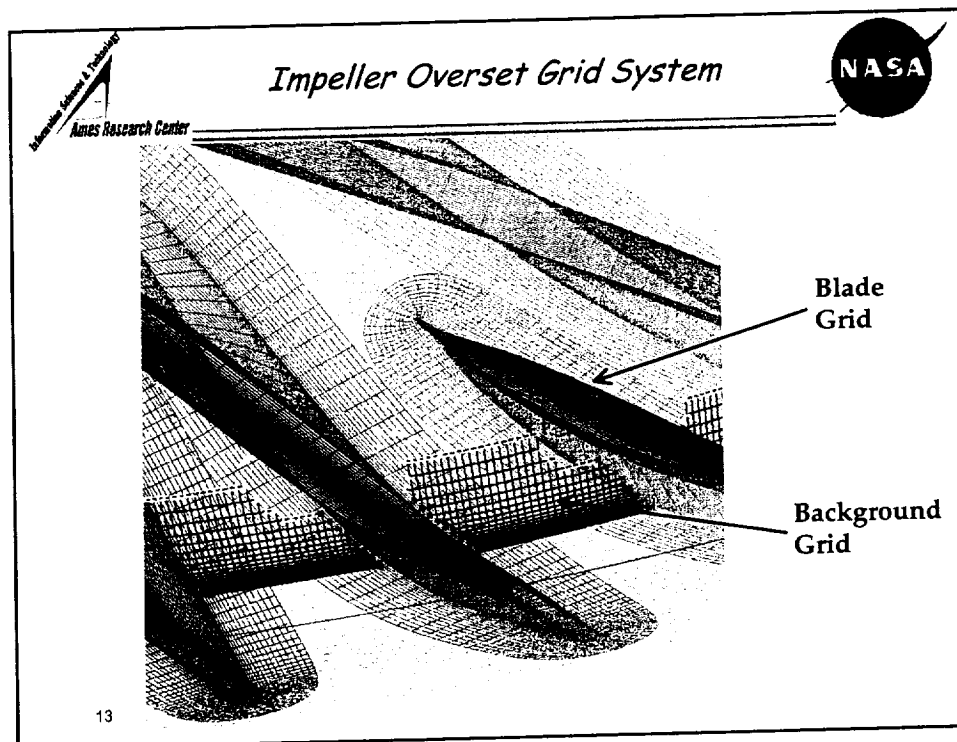
RLV 2nd Gen Turbopump

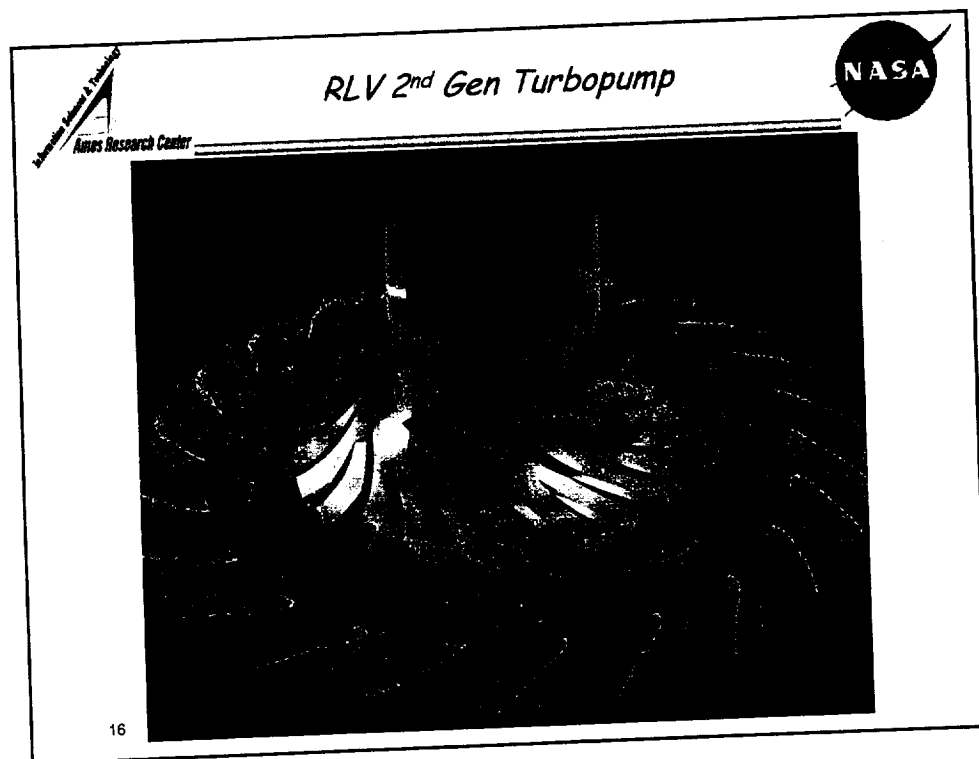
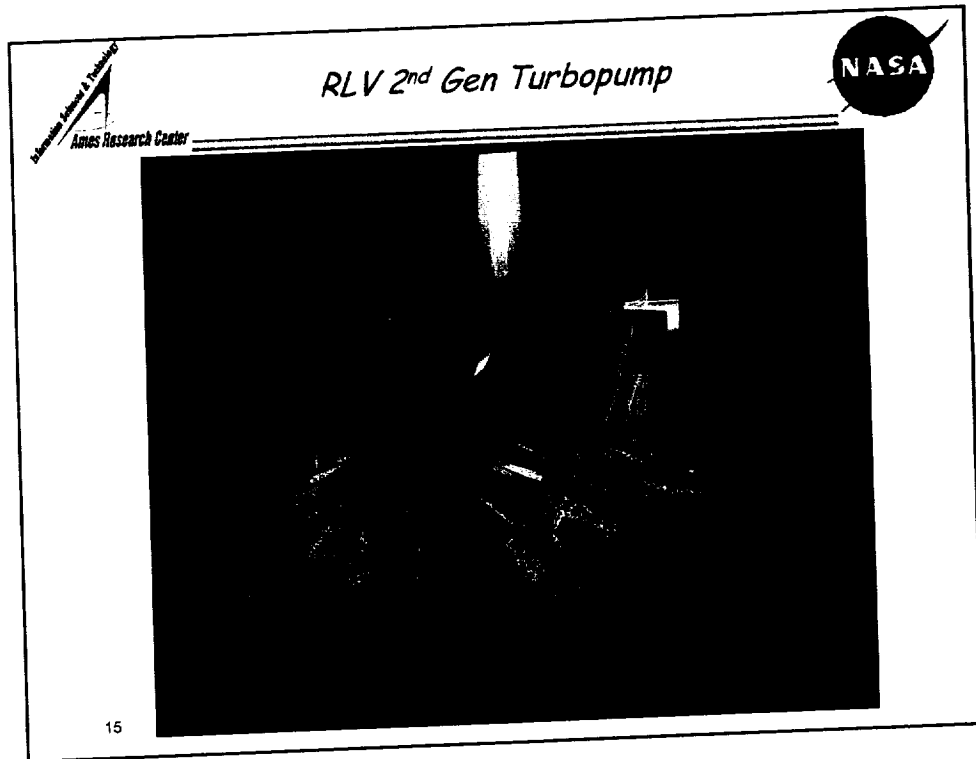
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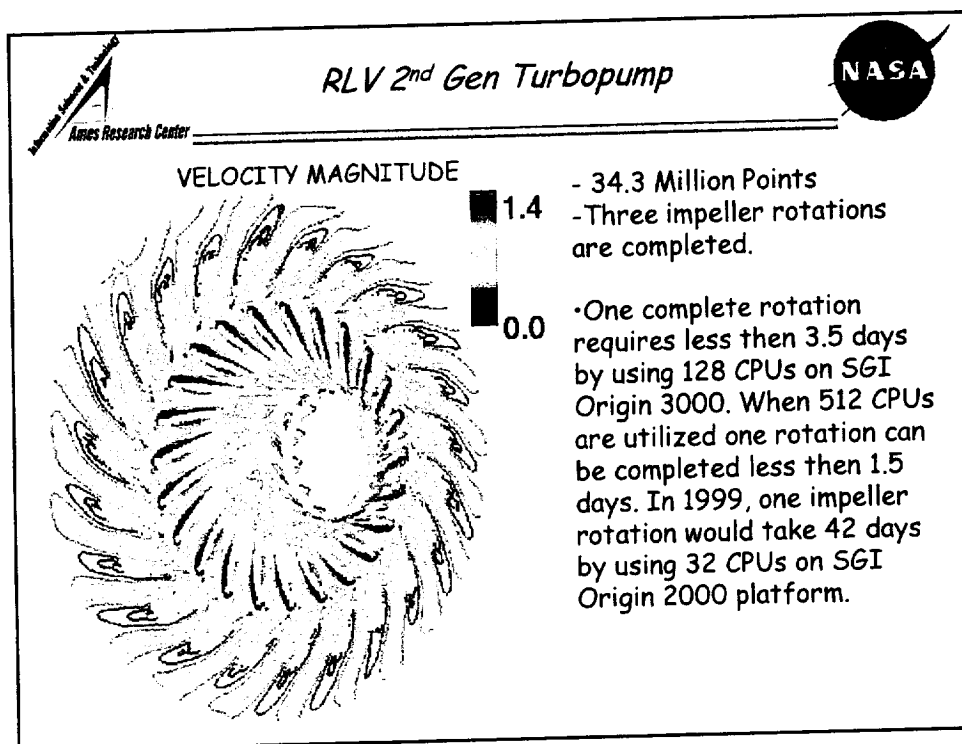
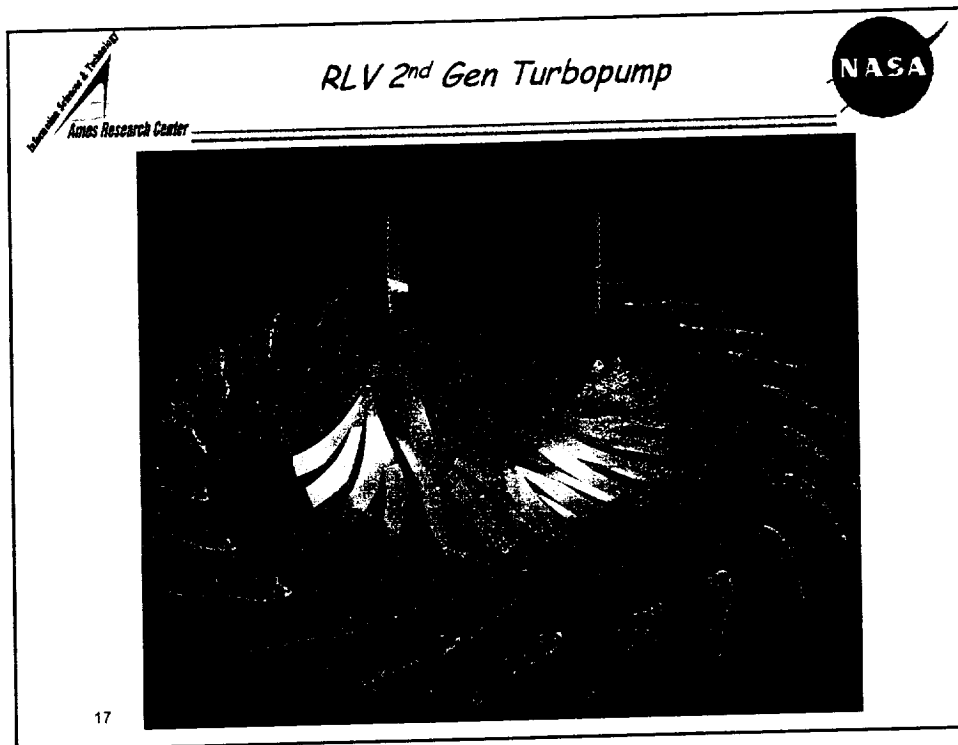


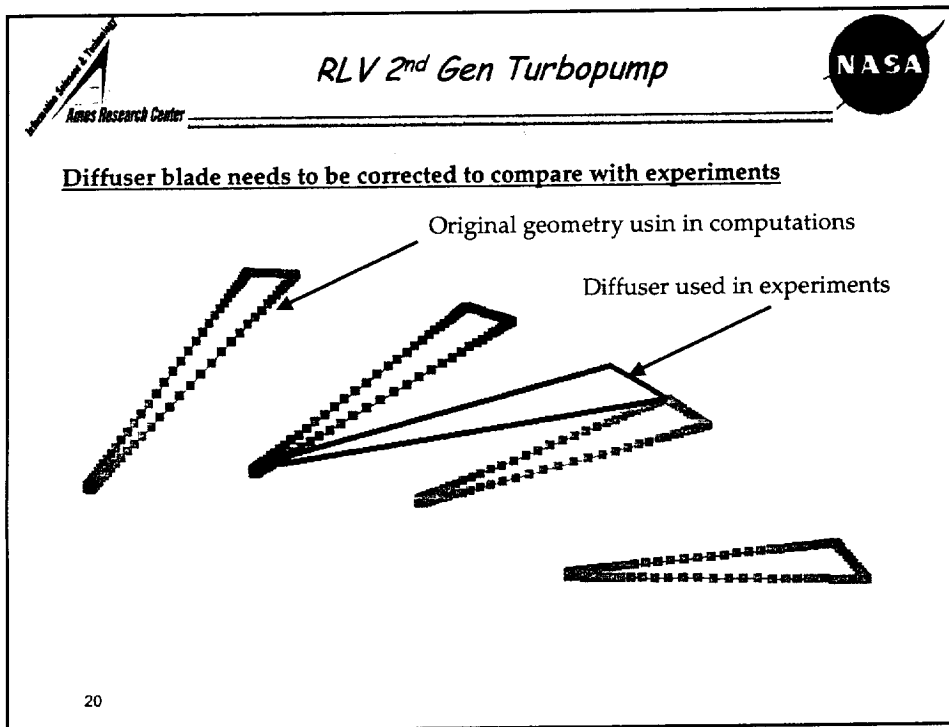
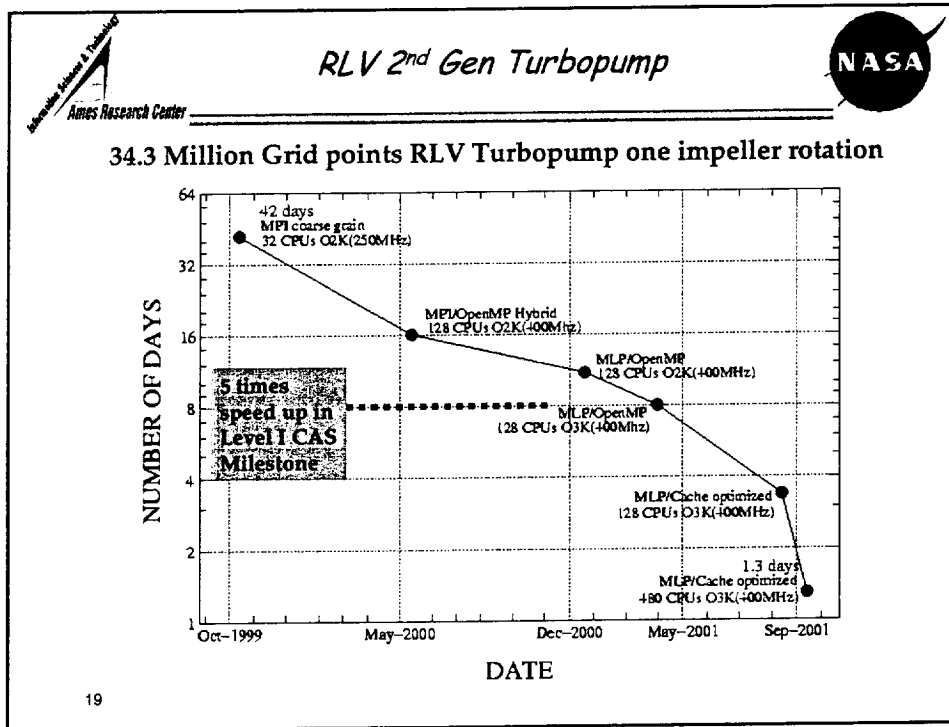
Unshrouded Impeller Grid :
6 long blades / 6 medium blades / 12 short blades
60 Zones / 19.2 Million Grid Points
Overset connectivity : DCF (B. Meakin)
Less than 156 orphan points.











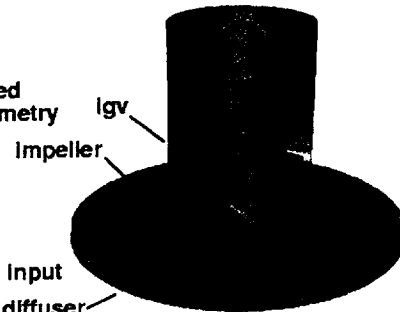
SCRIPT DEVELOPMENT FOR TURBOPUMP SIMULATIONS

Motivation

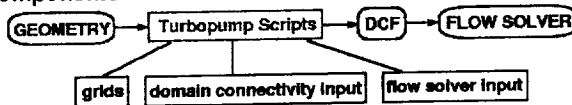
Significant user's effort needed
in complex process from geometry
to flow solver

Objective

Develop script system to
- generate grids
- create domain connectivity input
- create flow solver input
for different components
automatically



Approach



Develop one script for each component with ring interface
between components => easy plug in for different designs
and combinations of components

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SCRIPT GENERATION

Disadvantages

- > Require expertise to build scripts the first time

Advantages

- > Allow rapid re-run of entire process
- > Easy to do grid refinement and parameter studies
- > Easy to try different gridding strategies
- > Documentation of gridding procedure

Tcl scripting language

- > Works on UNIX, LINUX and WINDOWS
- > Integer and floating point arithmetic capability
- > Modular procedure calls
- > Easy to add GUI later if needed

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Scripting Capability

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INPUT AND OUTPUT

Input

- > profile curves for hub and shroud in PLOT3D format (rotated by script to form surface of revolution)
- > blade and tip surfaces in PLOT3D format
- > Parameters that can be changed
 - number of blades and sections
 - global surface grid spacing Δs (on smooth regions)
 - local surface grid spacing, some independent and some expressed as multiples of Δs (leading/trailing edges, etc.)
 - normal wall grid spacing (viscous, wall function)
 - marching distance
 - grid stretching ratio
 - ...

Output

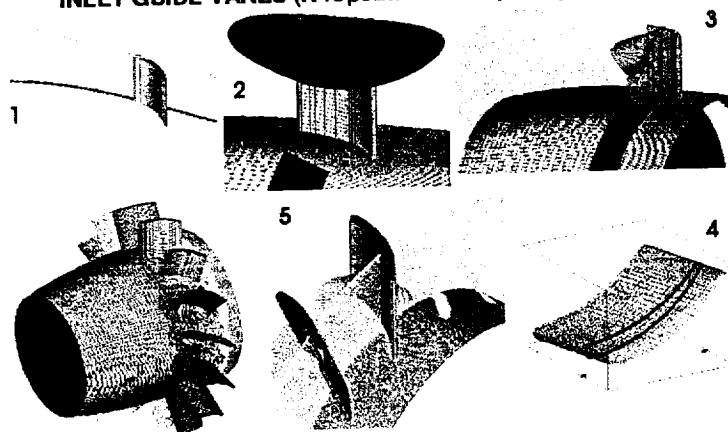
- > overset surface and volume grids for hub, shroud, blades
- > object X-rays for hole cutters using DCF
- > domain connectivity namelist input for OVERFLOW-D

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Scripting Capability

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INLET GUIDE VANES (N repeated blades, no tip clearance)



	Manual	Script (fine)	Script (coarse)
No. of pts (million)	7.1	5.8	1.1
User time *	1 day	43 sec.	20 sec.

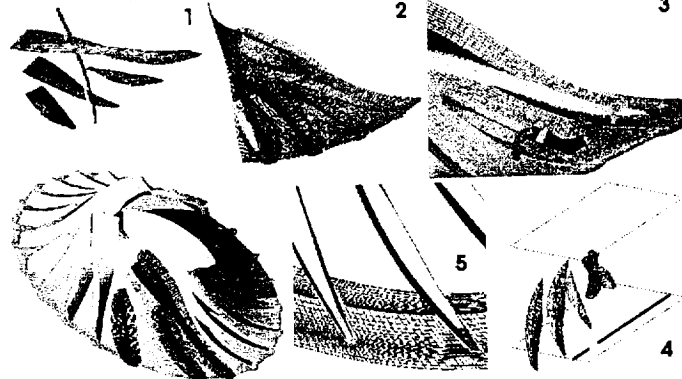
(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

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Scripting Capability

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IMPELLER
(M sections, N different blades in each section, tip clearance)



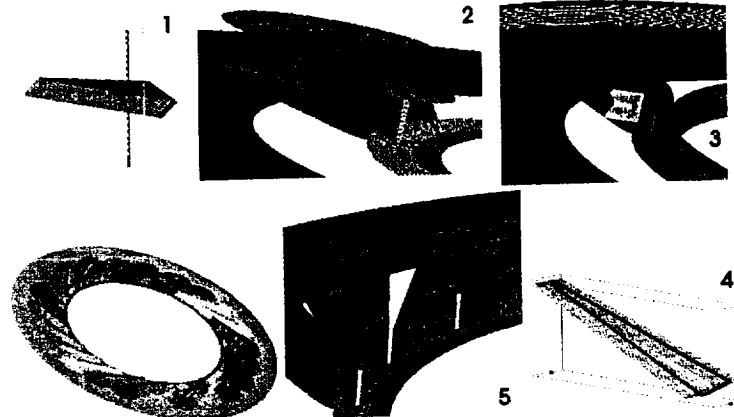
	Manual	Script (fine)	Script (coarse)
No. of pts (million)	19.2	15.2	8.8
User time *	~ 2 weeks	319 sec.	234 sec.
(* from geometry def. to DCF input with SGI R12k 300MHz CPU)			

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Scripting Capability

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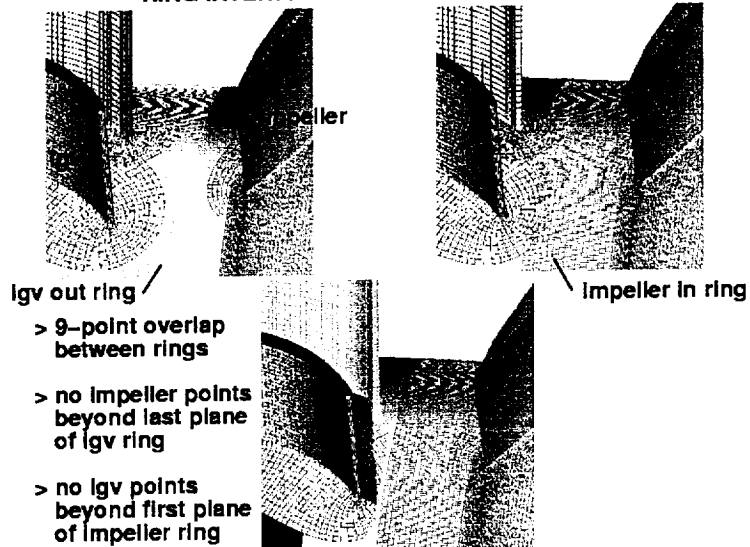
DIFFUSER (N repeated blades, no tip clearance)



	Manual	Script (fine)	Script (coarse)
No. of pts (million)	8.0	6.4	1.6
User time *	1 day	37 sec.	22 sec.
(* from geometry def. to DCF input with SGI R12k 300MHz CPU)			

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RING INTERFACE BETWEEN COMPONENTS



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FUTURE PLANS FOR TURBOPUMP SCRIPTING

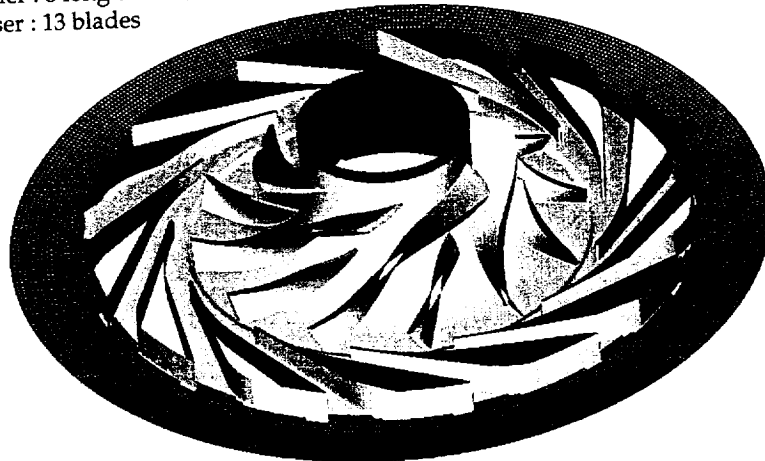
- > Flow solver input creation in scripts
- > Develop master script for connecting different components
- > Develop script for other components, e.g., volute, inducer
- > Perform more tests on different parameters
- > Improve robustness (error traps, wider range of cases)
- > Graphical interface front end

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Consortium Impeller-Diffuser



- Geometry and operating conditions obtained on January 24, 2002
(M. Williams @ Boeing, and D. Dorney NASA-MSFC)
- Impeller : 6 long blades / 6 short blades
- Diffuser : 13 blades

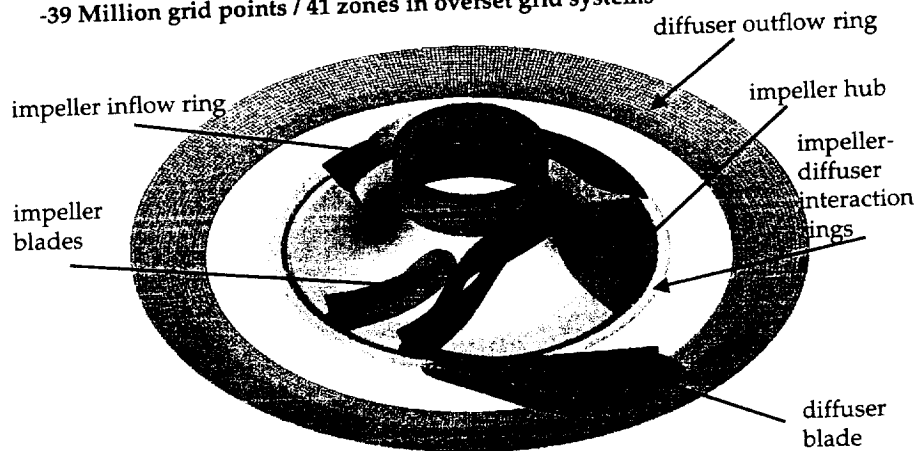


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Consortium Impeller-Diffuser



- Rotational speed : 6322 RPM / Mass Flow Rate : 1210 gallons/min.
- $Re : 1.37 \times 10^7$ / $L_{ref} = 4.5225$ inches, $V_{ref} = V_{tip} = 249.5$ ft/sec
- 39 Million grid points / 41 zones in overset grid systems



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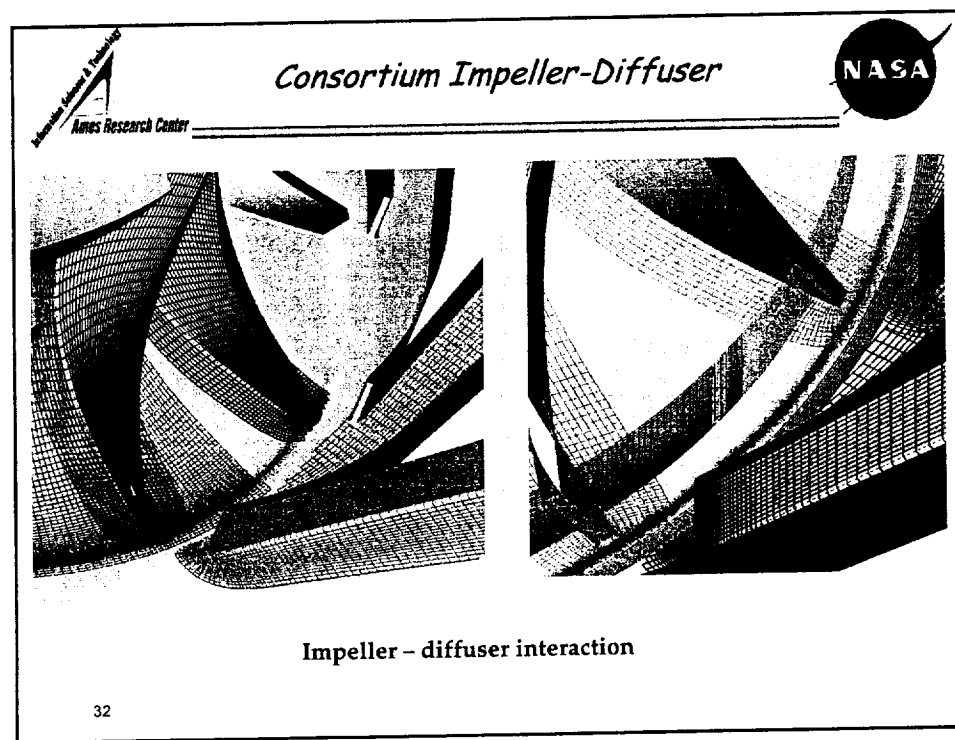
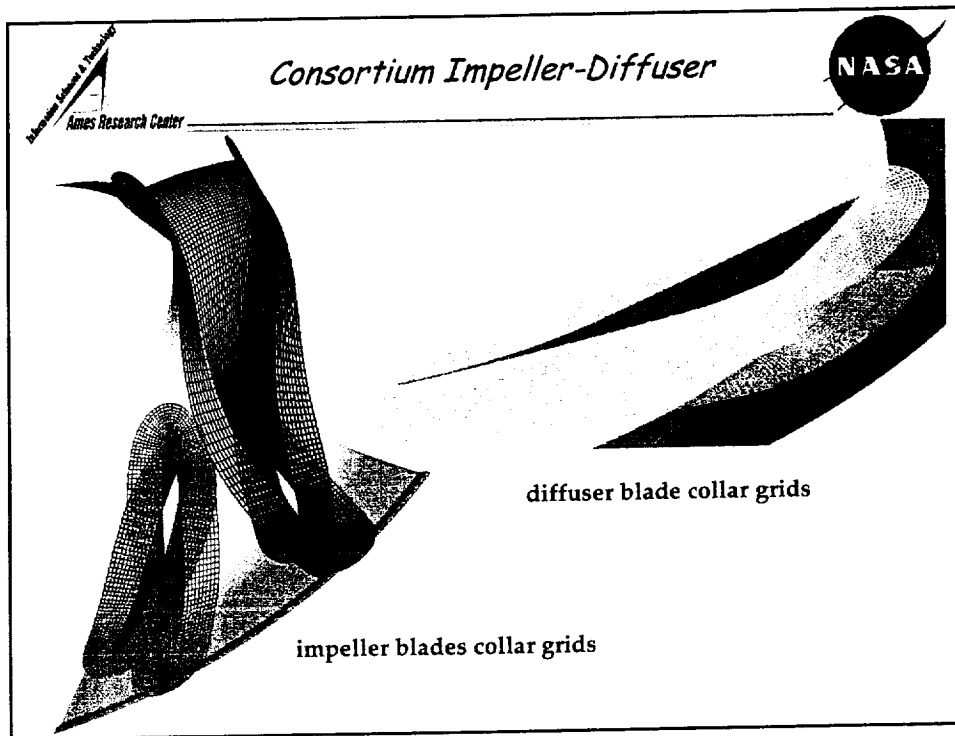
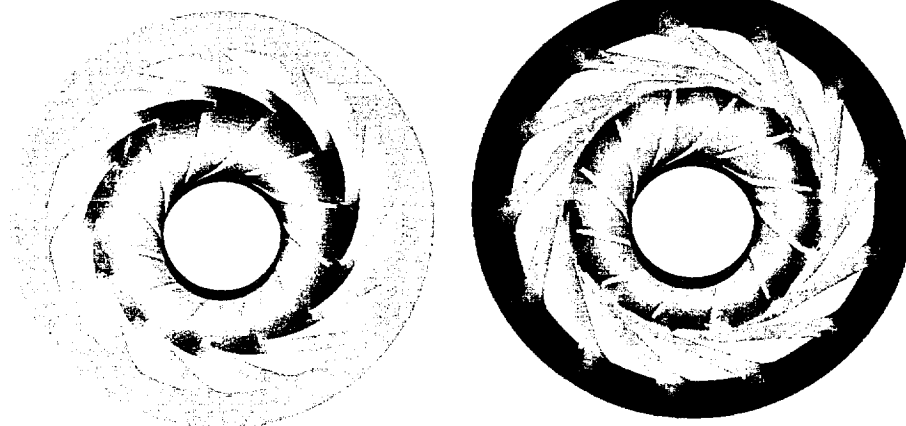


Figure 10 consists of two contour plots showing the pressure distribution on the upper and lower surfaces of a NACA 0012 airfoil. The left plot is for the upper surface and the right plot is for the lower surface. Both plots show pressure contours with a color scale from 0.000 to 1.000. The upper surface plot shows a high-pressure region (dark) at the leading edge and a low-pressure region (light) at the trailing edge. The lower surface plot shows a high-pressure region (dark) at the trailing edge and a low-pressure region (light) at the leading edge. The plots are labeled 'PRESSURE' and 'CONTOUR LEVELS'.

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total velocity surfaces



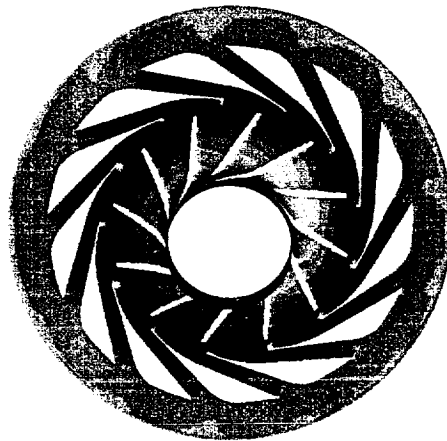
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Consortium Impeller-Diffuser

First Rotation : Impeller rotated 160 degrees.

pressure surfaces

total velocity surfaces



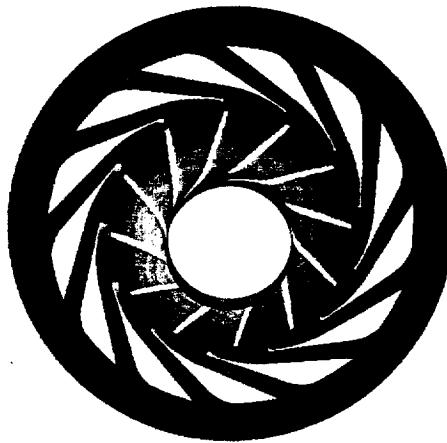
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Consortium Impeller-Diffuser

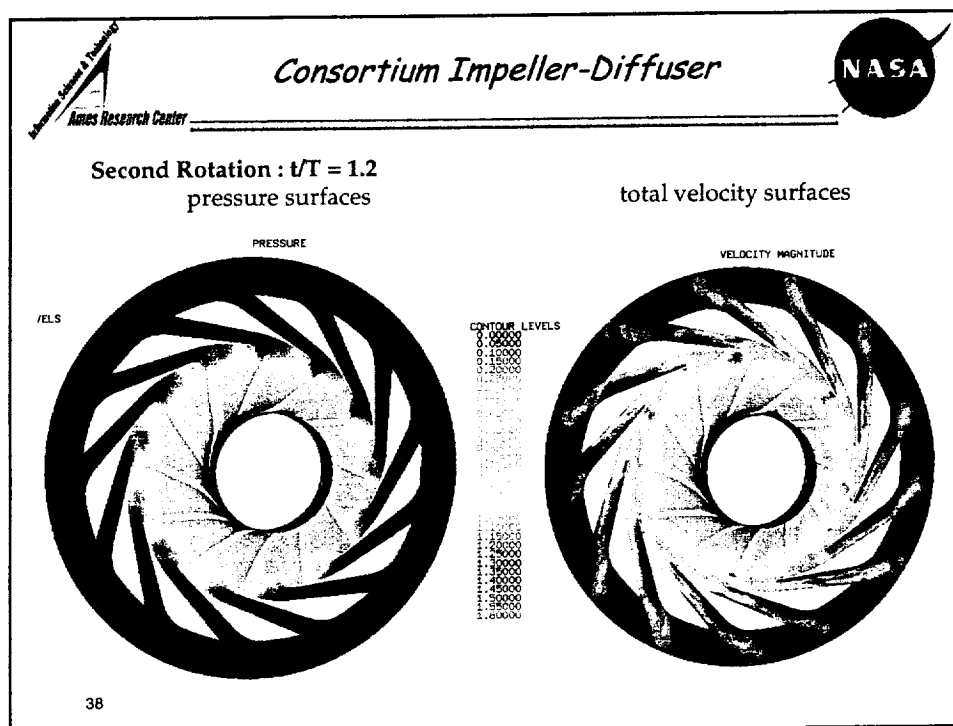
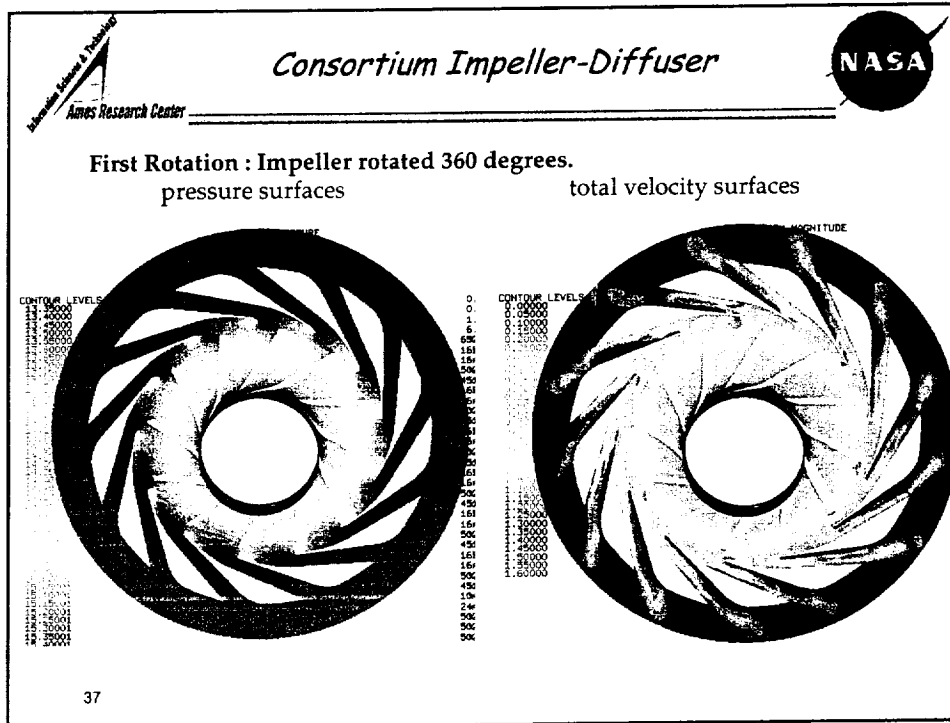
First Rotation : Impeller rotated 240 degrees.

pressure surfaces

total velocity surfaces



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Second Rotation : $t/T = 1.2$

velocity vectors near diffuser blade

VELOCITY COLORED BY VELOCITY MAGNITUDE

CONTOUR LEVELS
0.00000

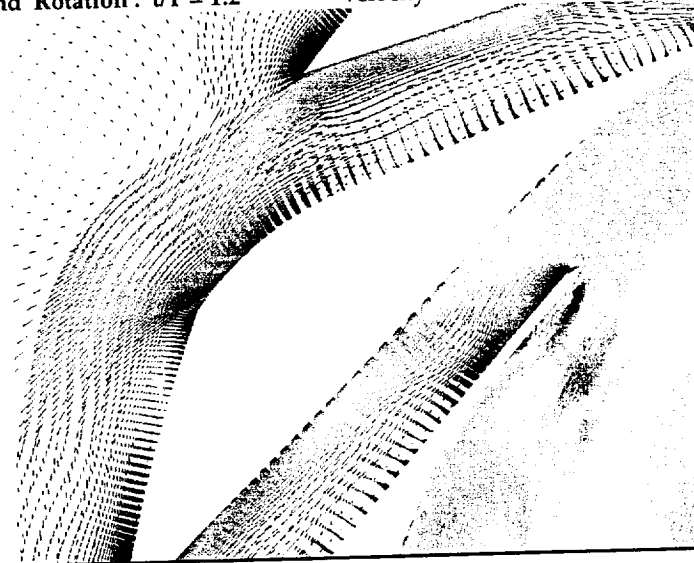
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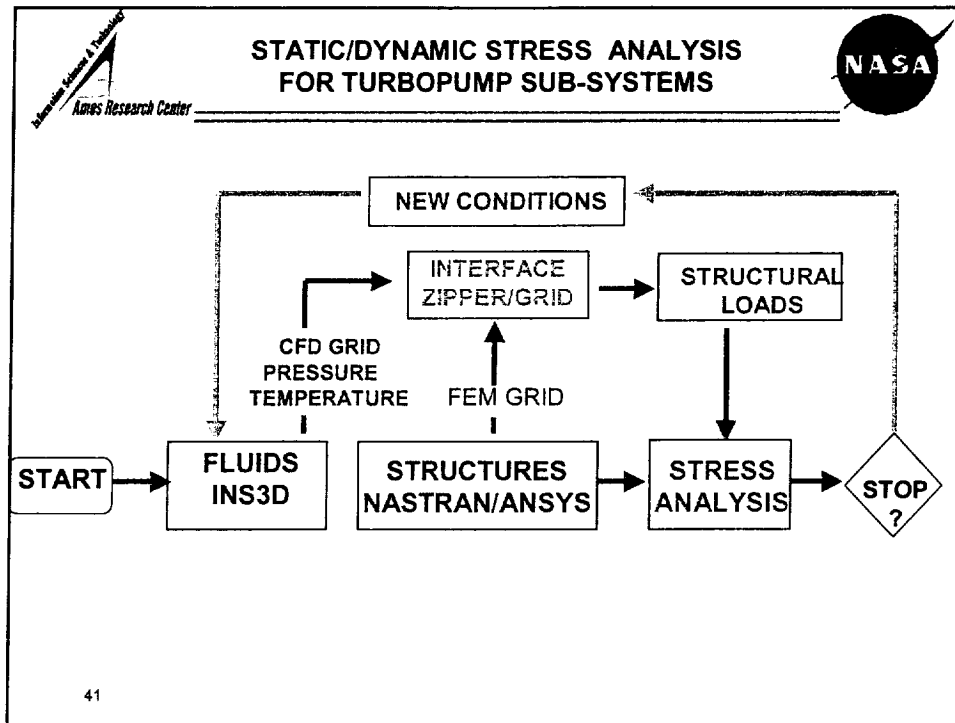
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Second Rotation : $t/T = 1.2$

velocity vectors near diffuser blade



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Summary

- Unsteady flow simulations for RLV 2nd Gen baseline turbopump for three impeller rotations are completed by using 34.3 Million grid points model.
- MPI/OpenMP hybrid parallelism and MLP shared memory parallelism has been implemented in INS3D, and benchmarked.
- For RLV turbopump simulations more than 30 times speed-up has been obtained.
- Moving boundary capability is obtained by using DCF module.
- Scripting capability from CAD geometry to solution is developed.
- Unsteady flow simulations for advanced consortium impeller/diffuser by using 39 Million grid points model are currently underway. 1.2 impeller rotations are completed.
- Fluid/Structure coupling is initiated.

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